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BROADBAND MEASUREMENTS OF UNDERWATER ACOUSTIC TARGET STRENGTHS --ETC(U)
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Technical Report 126

BROADBAND MEASUREMENTS OF UNDERWATER ACOUSTIC TARGET STRENGTHS OF PANELS OF TUNA NETS

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June 1977

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This research was funded by the Marine Mammal Commission and performed during calendar year 1976.

Released by
H. O. PORTER, Head
Biosciences Department

ACKNOWLEDGMENTS

Assistance for this project was provided by many people and institutions: Ocean Fisheries, Inc., The Porpoise Rescue Foundation, and Progressive Fishing Enterprises provided the nets. Leonard Orysiak and Arthur Huntly assisted with the measurements in TRANSDEC. Frank Alverson, Frank Awbrey, John Debere, R. J. Hoffman, Phillip Verne, R. L. Seeley, J. M. Speiser, D. E. Nelson, and F. G. Wood reviewed the manuscript.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NOSC/TR-123 (14)	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9) Technical rept. for
4. TITLE (and Subtitle) (6) BROADBAND MEASUREMENTS OF UNDERWATER ACOUSTIC TARGET STRENGTHS OF PANELS OF TUNA NETS		5. TYPE OF REPORT & PERIOD COVERED Research and Development CY 1976
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) J.S. Leatherwood, R.A. Johnson, D.K. Ljungblad, W.E. Evans		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Ocean Systems Center San Diego, California 92152		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS MM6AC020
11. CONTROLLING OFFICE NAME AND ADDRESS Marine Mammal Commission Washington, D.C. 20006		12. REPORT DATE (11) June 1977
		13. NUMBER OF PAGES 22 (12) 23 p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Sample panels of tuna nets of three different mesh sizes (1-1/4, 2, and 4-1/2 inches) and two twine types (twisted and braided) were placed in a nearly anechoic chamber, insonified with a broadband sound source, and the returns recorded and analyzed to determine target strength. Measurements were made with panels perpendicular to the source and with a 35-degree bend at the midline. Target strengths ranged from –21 dB to –4 dB for the perpendicular panels and from –23 dB to –16 dB for the bent panels. Two-inch braided net was the (cont on p 1473B)

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most reflective, though all panels produced sufficiently strong returns to allow porpoises to detect them acoustically.

CONTENTS

INTRODUCTION

Large but uncertain numbers of porpoises, primarily spotters (*Stenella attenuata*), spinners (*S. longirostris*), and white bellies (*Delphinus delphis*), are killed annually in the eastern tropical Pacific fishery for yellowfin tuna (*Thunnus albacares*). Since 1962, the estimates of total kill for a season have ranged from a high of 529,000 (1969) to 120,000 (1974) (Fox, 1976). The methods of fishing which result in the porpoise deaths have been widely described and discussed (e.g., Perrin, 1969; Green, Perrin, and Petrich, 1971). Attempts to reduce that mortality, conducted primarily by the National Marine Fisheries Service (NMFS) and the tuna industry, have concentrated on combinations of gear modifications and refinements in the associated fishing methods (see, e.g., NMFS Annual Reports, 1974 and 1975, and Coe and Sousa, 1972) and on the use of acoustics to modify the behavior of the porpoises to force them from the nets (NMFS Annual Reports, op. cit.).

After a temporary interruption in the acoustic research in 1972, there is now a resurgence of interest in using acoustics to help save porpoises. One line of planning has suggested that if segments of the net could be made more "acoustically visible" to the porpoises when they use their echolocation ability, the animals' frequency of contact and entanglement could be reduced. Available data on the porpoise species involved in the fishing do suggest that they incorporate sophisticated sonar systems of the types described for other pelagic delphinids (see Evans, 1973). But virtually nothing is known of their ability to hear and use acoustic signals in the noise environment of a typical purse seining operation and, in addition, the acoustic characteristics of the nets in use are not known. Before the regulatory agencies require or even recommend that the industry utilize small mesh sizes or changes in net material for reasons other than prevention of entanglement, the acoustic reflectivities of those materials and their relative probabilities of being "seen" acoustically should be known.

This paper reports on broadband laboratory measurements of the acoustic target strengths of panels of tuna nets of three mesh sizes, 1-1/4, 2, and 4-1/2 inches, using two presentations, flat (0 degrees) and bent (35 degrees). In addition to plain panels, we measured one combination panel with 2-inch braided net for the upper half laced together with 2-inch knotless for the lower half. Four-and-one-half-inch mesh is used for 90 percent or more of the current tuna seines. Two-inch mesh has been used for the past five years as the "Medina-panel" in the backdown area. One-and-one-quarter-inch mesh will be required as a replacement to the two-inch mesh for the 1977-78 fishing season (NMFS, 1976).

MATERIALS AND METHODS

DATA COLLECTION

1. Physical Configuration of the Test Apparatus

All measurements were made in the Naval Ocean Systems Center's Transducer Evaluation Center (TRANSDEC), a nearly anechoic test and calibration facility located on Point Loma, San Diego, California. TRANSDEC is about 180 feet long, 140 feet wide, and a maximum of 30 feet deep.

For these measurements, the sound projector and the monitoring instrumentation were placed in the configuration shown in figure 1. The sound was delivered through a specially constructed projector (Applied Research Laboratories, University of Texas) with a nominal center frequency of 80 kHz. This projector was previously utilized in a biosonar study (Fish, Johnson, and Ljungblad, 1976). Directivity patterns of this projector at 60 kHz and 120 kHz are shown in figure 2. The width of the horizontal and vertical patterns aided in determining the placement of the net samples relative to the projector. Both incident and reflected signals were monitored on a hydrophone sensitive over a range encompassing all the frequencies tested. The various samples of net to be measured, listed in table 1, were placed in a specially constructed framework measuring 2.8-m wide by 3.2-m tall (see figure 1). Each side was hinged in the middle so that the net sample could be measured both perpendicular to the axis of the sound beam and with a 35-degree bend in the frame sides so that the net was no longer flat. The framework was suspended from flotation, so that the center was at the main axis of the sound beam, and was also anchored to the bottom. Carpenter's levels attached to the frame were checked periodically to insure that samples were correctly oriented. Holding pins all around the net frame permitted the nets to be measured at "normal" mesh sizes and in stretched configurations. Nine different net panels were measured.

2. Measurements

The sound projector was excited by a single-cycle electrical sine wave of 100 kHz. This pulse was generated by a waveform generator, which also provided a synchronization pulse. A multifunction generator provided triggering and timing so that the sine-wave pulse could be repeated once per second. The actual waveform projected was markedly not a single-cycle sinusoid but rather the response of the source transducer to the brief electrical signal. This was the desired effect. Typical echolocation pulses from odontocetes are very brief and broadband. That is, the distribution of signal energy vs. frequency is broad (usually an octave or more). However, echolocation pulses are extremely varied in pulse shape and duration (Evans, 1973), even for an individual animal. The bandwidth can be in excess of 100 kHz. Based on this feature of large bandwidth as the important characteristic of echolocation pulses, we chose to produce a broadband pulse in the manner just described. Signal processing theory does not require that our pulse reproduce any particular echolocation pulse because broadband target strengths are normalized for each incident signal. In theory,

Table 1. Summary of measurements by net type; for convenience, references to trials in text and figures utilize numbers listed for data and results.

Sample	Data	Results	COMMENTS
projected energy spectrum	FFT 1		
projected energy spectrum	FFT 1a		
noise	a	aa	
noise	b	bb	
frame without net	c	cc	
1-1/4" braided net	1	1a	0° only
2" braided net	2	2a	0°, day 1
2" braided net	3	3a	35°, day 1
4-1/2" braided net	4	4a	0°
4-1/2" braided net	5	5a	35°
4-1/2" twisted net	6	6a	0°
4-1/2" twisted net	7	7a	35°
1-1/4" twisted net	8	8a	0°, day 1
1-1/4" twisted net	9	9a	35°, day 1
1-1/4" twisted net	10	10a	35°, day 2
1-1/4" twisted net	11	11a	0°, day 2
2" braided net	12	12a	0°, day 2
2" braided net	13	13a	35°, day 2
2" knotless - 2" braided net	14	14a	0°
2" knotless - 2" braided net	15	15a	35°
stretched 2" braided net	16	16a	0°
stretched 2" braided net	17	17a	35°

given a totally anechoic environment and appropriate transducers, swept frequency sinusoidal signals would have given equally valid target strengths.

The synchronization pulse from this system was compatible with existing TRANSDEC instrumentation so that all analysis and recording instrumentation was synchronized with the sound source. The TRANSDEC system was used to set up and monitor the experiment by waiting appropriate time intervals for the reception of both the incident and the reflected signals. All signals were received on the same hydrophone, as shown, which simplified calibration procedures.

Signals were monitored on an oscilloscope, from which sample photographs were made of incident and reflected signals from each net sample examined. Signals were also recorded on a broadband tape recorder for later analysis. Recordings were made at 60 in/sec on 2 channels, one at full amplified level and one attenuated by 20 dB below that level. A third channel recorded the synchronization pulse to aid later analysis. The tests which were conducted are indicated in table 1.

DATA ANALYSIS

The recorded signals were analyzed using standard digital signal processing techniques on a computer. The tap[illegible] played back at 3-3/4 in/sec (16:1 slowdown) for digitizing. The synchronization [illegible] fed to a Schmitt trigger which initiated a timing sequence. The attenuated sign[illegible]cted through a bandpass filter (24 dB per octave) whose passband was set at [illegible] to 12.5 kHz with no gain (equivalent to 40 kHz to 200 kHz before slowdown). This provided an incident pulse level of about 2 volts peak-to-peak. The unattenuated signal was connected through an identical filter with 20-dB gain and the same frequency settings and then through an adjustable attenuator. For each net configuration the attenuation was adjusted to give about a 2-volt peak-to-peak echo level. In this way, both the incident pulse and received echo were digitized using the full 12-bit resolution of the analog-to-digital converter. The software timing sequence initiated the converter at 40,000 samples per second to collect 1024 samples of the signal at the appropriate time and then 1024 or 2048 samples of the echo depending on the nominal echo length and the difficulty of identifying the echo in the background system noise. Eight successive sequences were digitized and stored for each net configuration.

Each signal and echo were analyzed with a 2048-point fast Fourier transform (FFT) with no special windowing (these are transient signals). Those data frames with only 1024 points were padded with zeros. The relative energy spectrum was then computed. After compensating for recording levels, filter gains, and spherical spreading, the echo was normalized according to the incident signal energy spectrum to provide the broadband target strength data. Eight results were averaged for each net configuration, although little variation was seen for individual calculations.

The target strength is defined to be the equivalent sound pressure level one meter from the target referred to the sound pressure level incident on the target, expressed in decibels (dB):

$$TS = 10 \log \frac{E\ (\text{received at 1 m})}{E\ (\text{incident})} ,$$

where E is sound energy (Urick, 1977). The definition does not imply that the sound pressure should be measured at 1 meter, but rather that it should be observed at a range at which the target appears to be a point source and then referred back to 1 meter.

The units of target strength are dB since the reflectivity and geometry of all possible targets would otherwise allow many orders of magnitude of variation for this quantity. Because target strength varies over the frequency range used by porpoises, target strength must be determined as a function of frequency.

RESULTS

The results from all test runs are graphically displayed in figure 3. The first column represents the signal and echo, the second column, target strength.

The plot in figure 3 labeled FFT 1 (see table 1 for all notations) shows the energy spectrum of the incident pulse to 30 dB below peak level. FFT 1a is an expanded plot over the 60-kHz to 160-kHz frequency range, where the incident signal energy was prominent and thus where the calculations were most valid. All results are presented over this 100-kHz frequency band.

Plot aa in figure 3 is the equivalent "target strength" calculation for the system noise alone as the "echo" to indicate the bottom range the system was capable of measuring for a 1024-point noise sample. Result bb is for a 2048-point noise sample. Results c and cc are for the empty net frame. Contributions from this frame were significant in the 120-kHz to 150-kHz range. All these results indicate an anomaly around 150 kHz of unknown origin. For comparison to the net data, the frame alone data should be used.

The remainder of the results in figure 3 are for the various net configurations as indicated. The signal and echo components are not contiguous time segments but are plotted as such for convenience. Likewise, the amplitude scales are different, representing the effort to fully utilize the 12-bit converter for both the signal and the echo. Most of the nets showed a dramatic structured pattern of maxima and minima which can be explained as the interference one would expect from any regular lattice-type structure. Where the interference is broken up, as in the 35-degree bend configurations, the structured pattern is much less evident. In addition, the "flatness" of the zero-degree configurations yielded generally higher target strengths over the 35-degree configurations. Many of the results from the 35-degree configurations are marginally valid as compared to the frame alone. Since there are regions of marked structure in the target strengths for these configurations, it appears that these target strengths were near that of the frame alone and not significantly below that level. For

a quick comparison, table 2 lists the mean target strength values over the 100-kHz band of frequencies, but it should be emphasized that the full plots are far more meaningful and should be used for all detailed comparisons. In addition, a rank ordering of the net target strengths is indicated for the 0-degree configurations. The data for the 1-1/4-inch twisted net and the 2-inch braided net were taken twice (on successive days). While the mean target strengths compare favorably day to day, the structured patterns do not, suggesting that the system was very sensitive to the exact placement of the net for fine structure analysis.

Table 2. Mean target strength values for various trial runs.

Net and configuration	Target strength, dB	Rank order
1-1/4" braided, 0°	-15	8
2" braided, 0°, day 1	-10	4
2" braided, 35°, day 1	-17	
2" braided, 0°, day 2	-7	2
2" braided, 35°, day 2	-16	
4-1/2" braided, 0°	-14	7
4-1/2" braided, 35°	-20	
4-1/2" twisted, 0°	-21	9
4-1/2" twisted, 35°	-23	
1-1/4" twisted, 0°, day 1	-12	5
1-1/4" twisted, 35°, day 1	-23	
1-1/4" twisted, 0°, day 2	-13	6
1-1/4" twisted, 35°, day 2	-23	
2" knotless and 2" braided, 0°*	-4	1
2" knotless and 2" braided, 35°*	-17	
2" braided stretched, 0°	-9	3
2" braided stretched, 35°	-16	

*Equal sized panels laced together with seam in middle of frame parallel to water surface.

DISCUSSION

Compared to the results of Wellsby and Goddard (1973), these nets had much larger target strengths as expected from both twine size and sample size considerations. Wellsby and Goddard, on the other hand, were only interested in materials which minimized target strength and also they made single frequency measurements at 507 kHz and 986 kHz. Our results indicate the fallacy, particularly at the frequencies of interest for marine mammals, of making single frequency measurements if one wishes to examine the fine structure of the target strength. These results more closely duplicate those expected for a marine mammal using its own broadband echolocation system.

These results on target strength indicate more than just that a porpoise will "see" one net and not "see" another. Clearly, since we have been able to measure target strength for all these nets, they will all be "visible" to some degree to a porpoise under ideal circumstances. The importance of the measurements is how well the porpoise can "see" one net compared to another net.

For example, sound disperses in the ocean by spreading spherically from an ideal sound source. This means that each doubling in distance from the source reduces the sound level by 6 dB. A similar relationship occurs for the sound reflected from a target. Hence, the doubling of distance from a target will result in a 12-dB reduction in echo level, all other factors being equal. Alternatively, another target with 12-dB greater target strength would bring the echo strength back to the initial level were it to be used at the doubled distance.

A very crude calculation can be made to get an estimate of the detectability of any target from porpoise hearing data. Assume the sound pressure level projected by a porpoise is 160 dB re 1 micropascal at 1 meter and that the hearing sensitivity in the range of interest is 60 dB re 1 micropascal. Then a 0-dB target would just be detectable at a distance of 256 meters (one-way propagation loss of 48 dB neglecting attenuation) at 4 dB above the assumed threshold. A −12-dB target would be detectable only out to about 128 meters or half as far.

The measurements suggest that porpoises utilizing their echolocation systems should be able to easily "see" any of the mesh sizes measured regardless of the angles at which they are oriented toward them and regardless of the degree of stretch in the nets. In the configurations where our data are most valid (primarily the 0-degree configurations), we do find significant differences in the mean target strengths of the nets (a 17-dB range). In the complex acoustic environment of the purse seine, it may very well be that a 17-dB more detectable net would present a significant advantage for the porpoise, considering the configurations and clutter (other targets) which are possible.

Of the samples we measured, the 2-inch braided net consistently gave the highest target strengths (including the laced combination with the 2-inch knotless). Whether or not this acoustic advantage is exploitable remains to be tested under more realistic conditions and in light of other fishing strategies. It may very well be that all these nets are as acoustically "visible" as necessary to the animals and other factors predominate in the mortality problem.

ACKNOWLEDGMENTS

Assistance for this project was provided by many people and institutions: Ocean Fisheries, Inc., The Porpoise Rescue Foundation, and Progressive Fishing Enterprises provided the nets. Leonard Orysiak and Arthur Huntly assisted with the measurements in TRANSDEC. Frank Alverson, Frank Awbrey, John Debere, R. J. Hoffman, Phillip Verne, R. L. Seeley, J. M. Speiser, D. E. Nelson, and F. G. Wood reviewed the manuscript. This research was funded by the Marine Mammal Commission.

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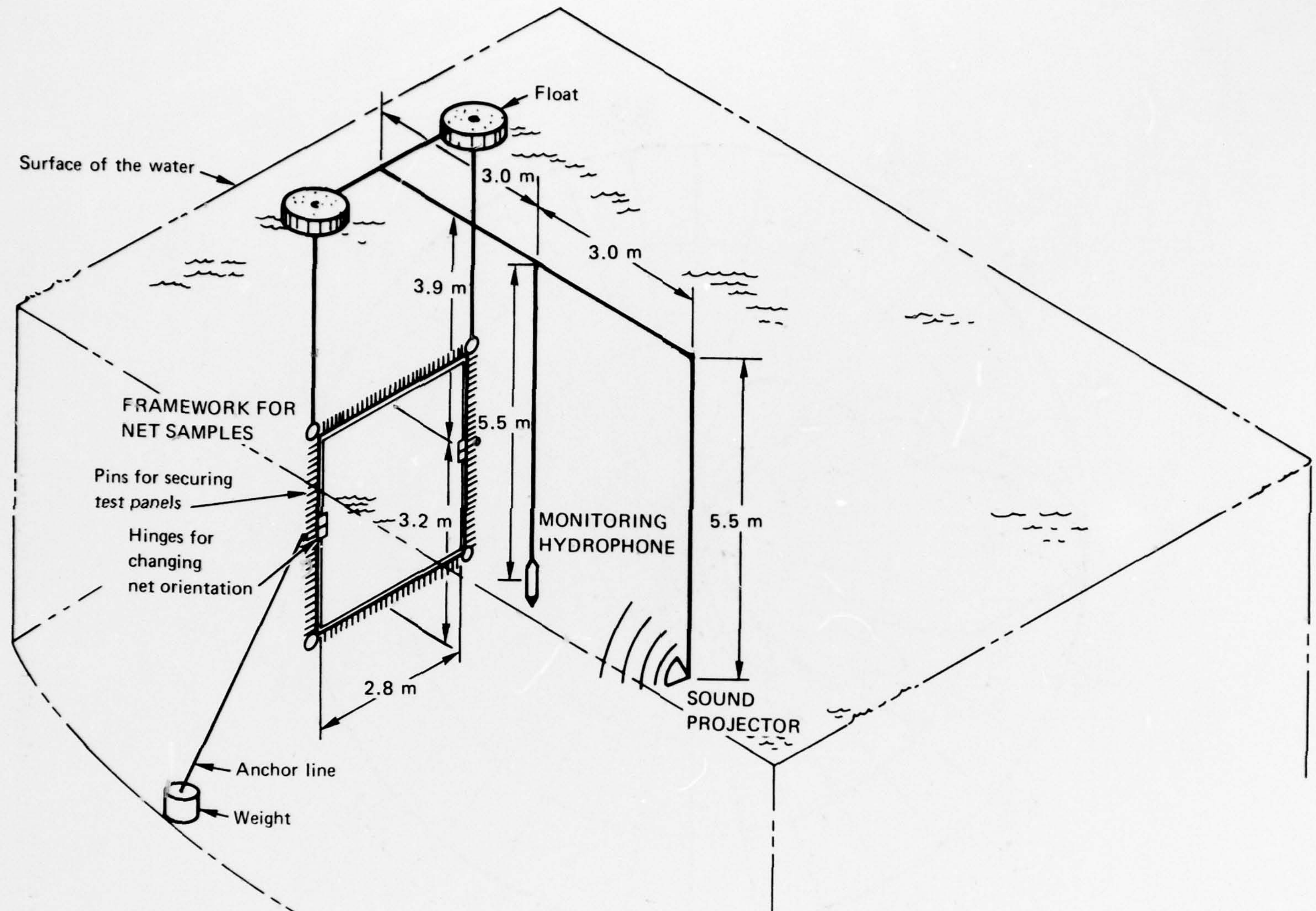


Figure 1. Configuration of TRANSDEC measuring system, showing relative positions of sound projector, monitoring, hydrophone, and framework.

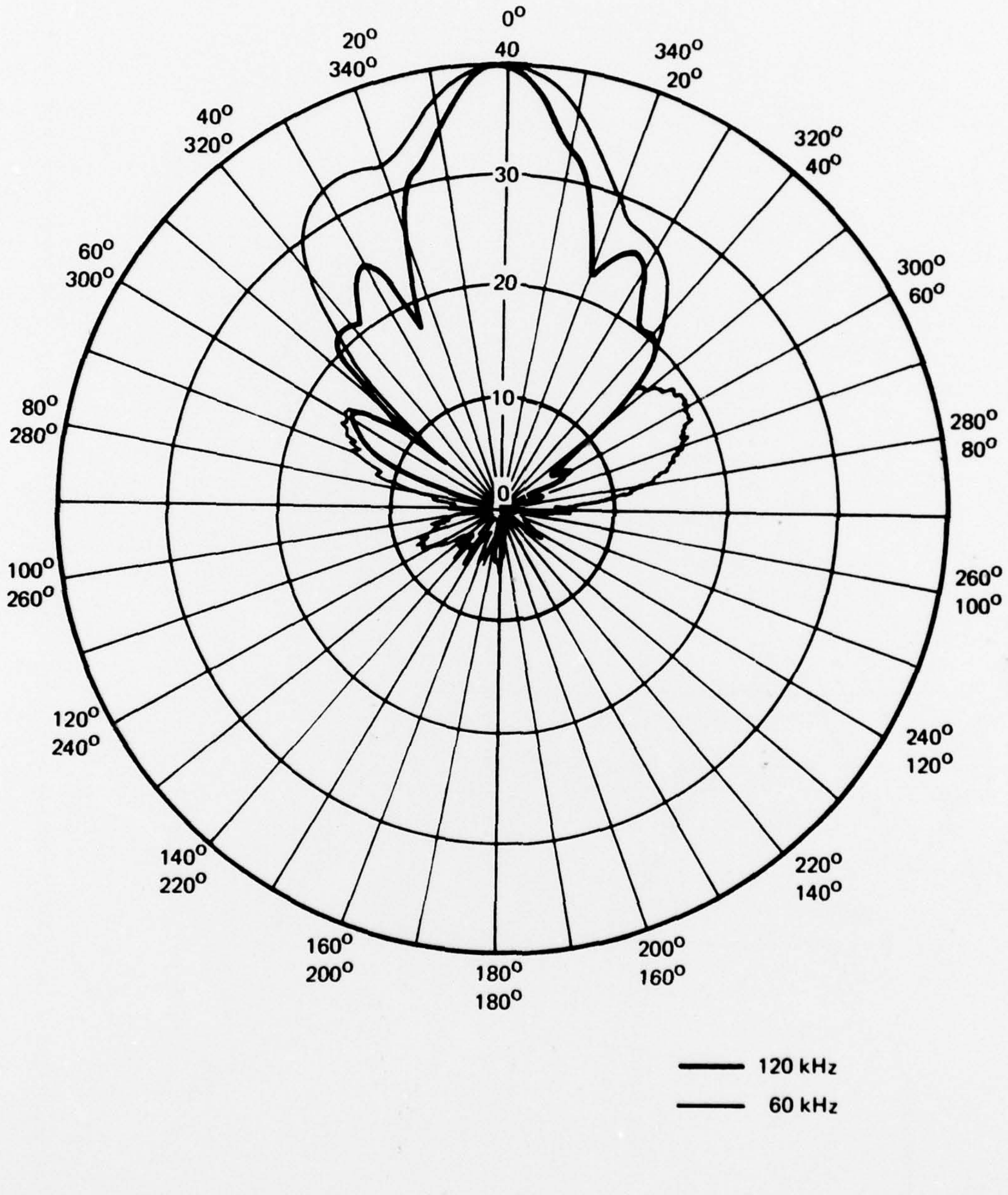


Figure 2. Directivity patterns of ARL projector at 60 kHz and 120 kHz.

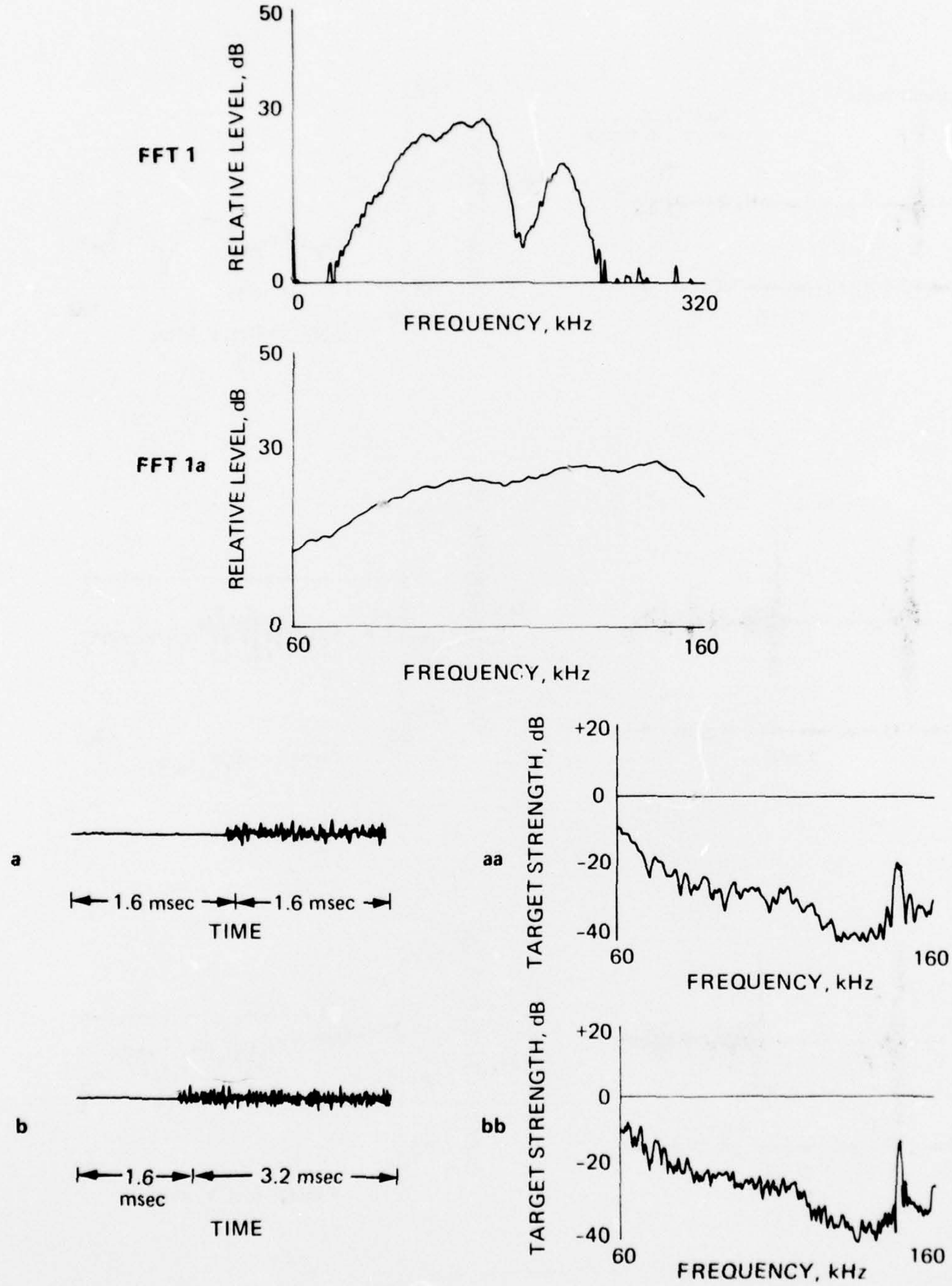
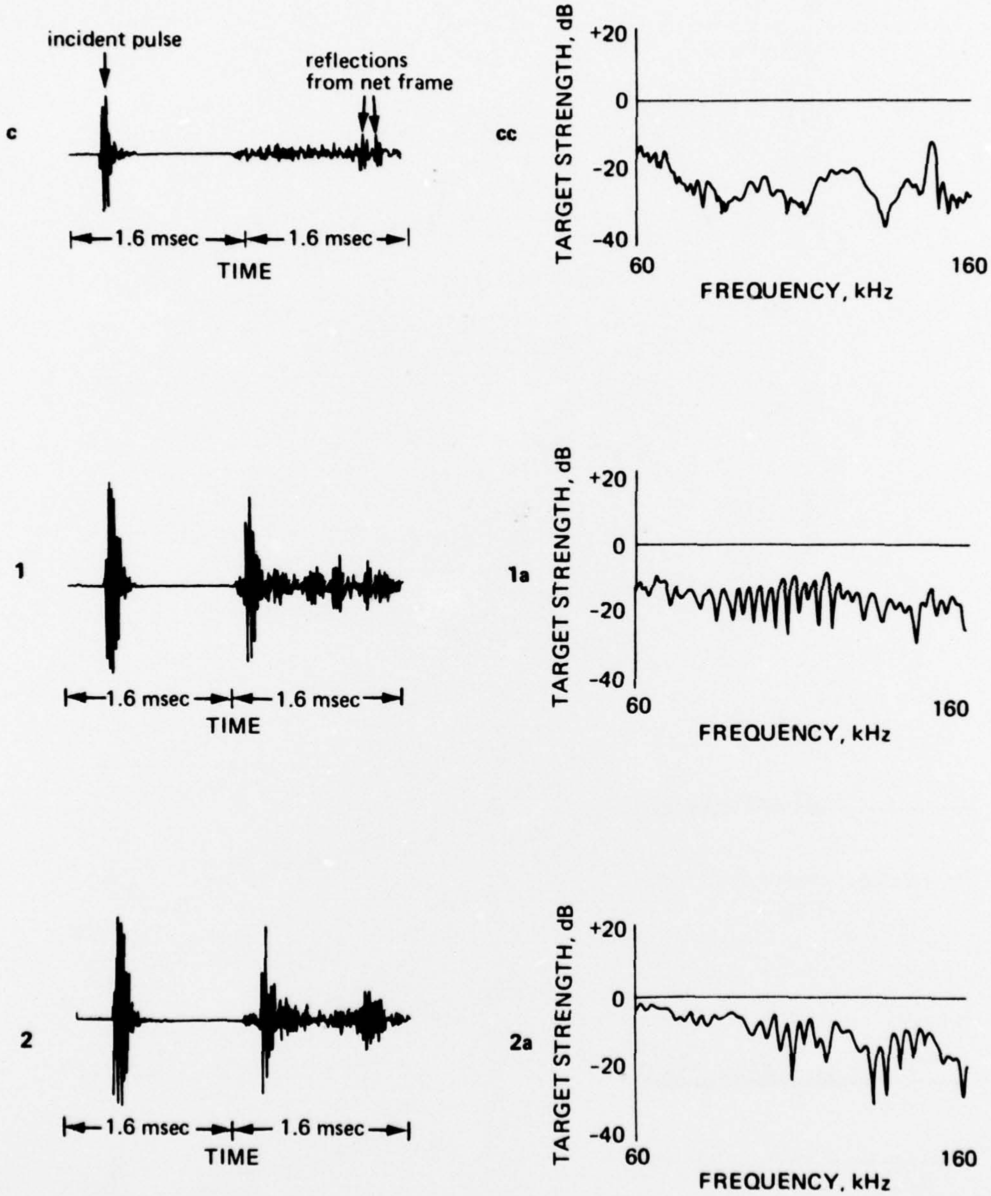


Figure 3. Results of net measurements.



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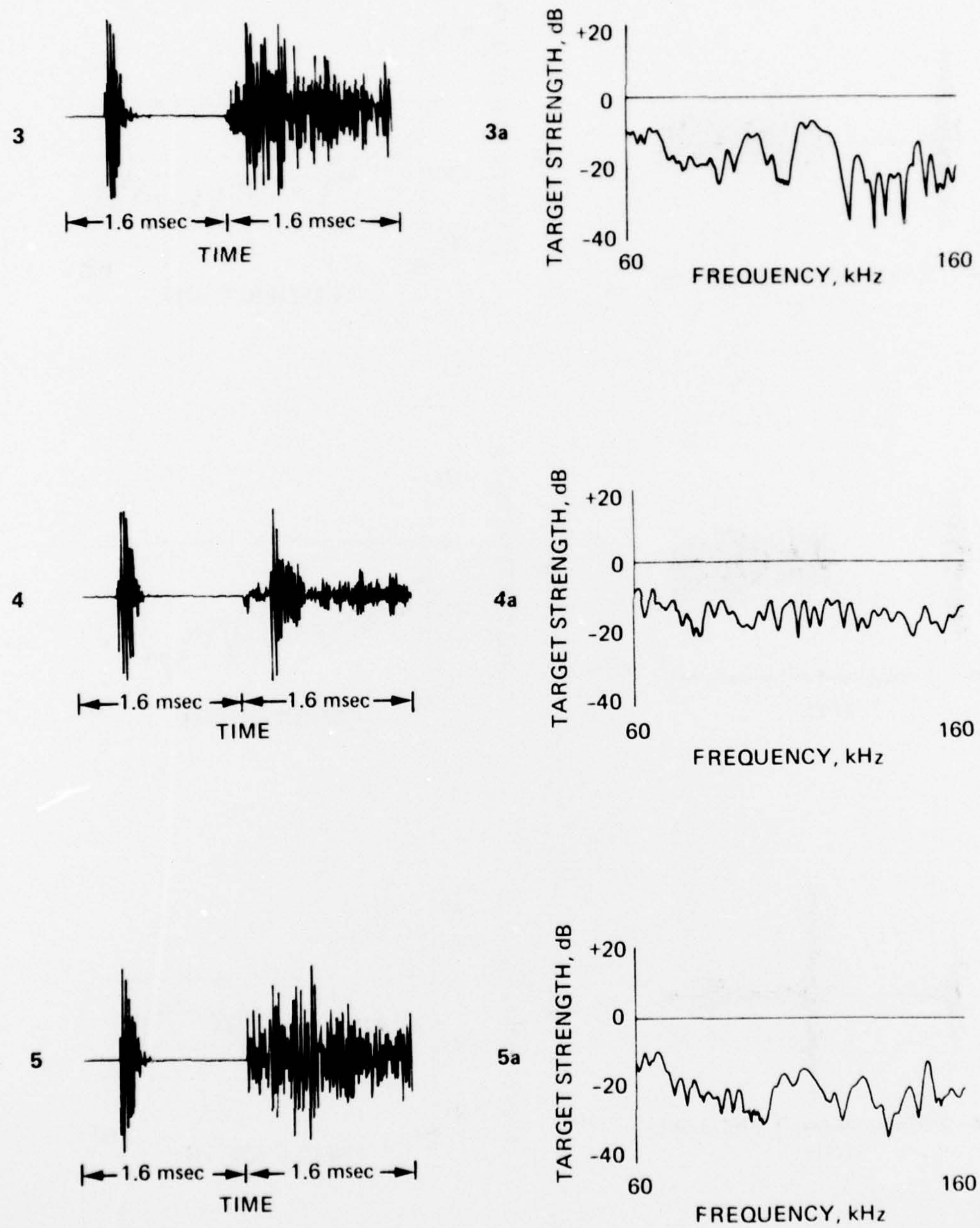

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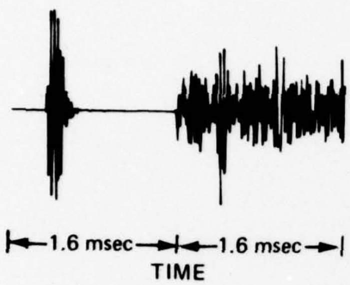

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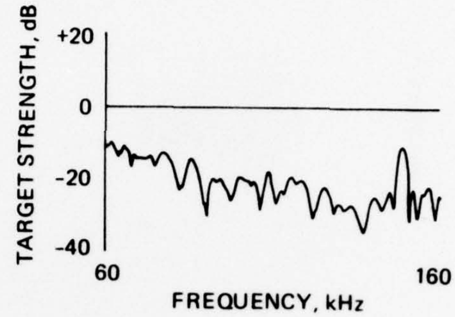

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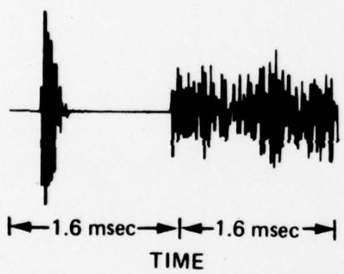

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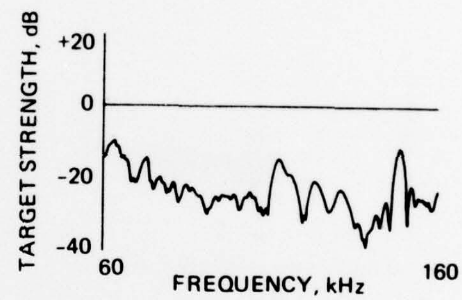

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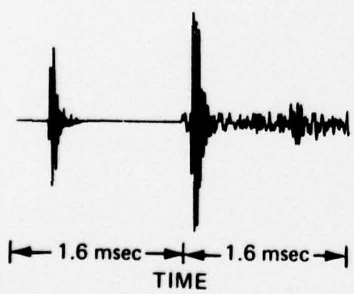

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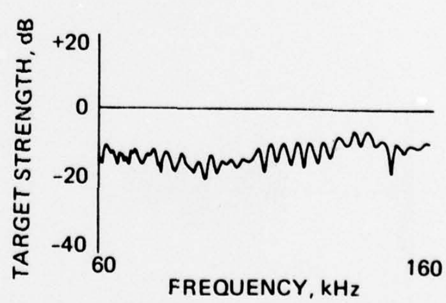

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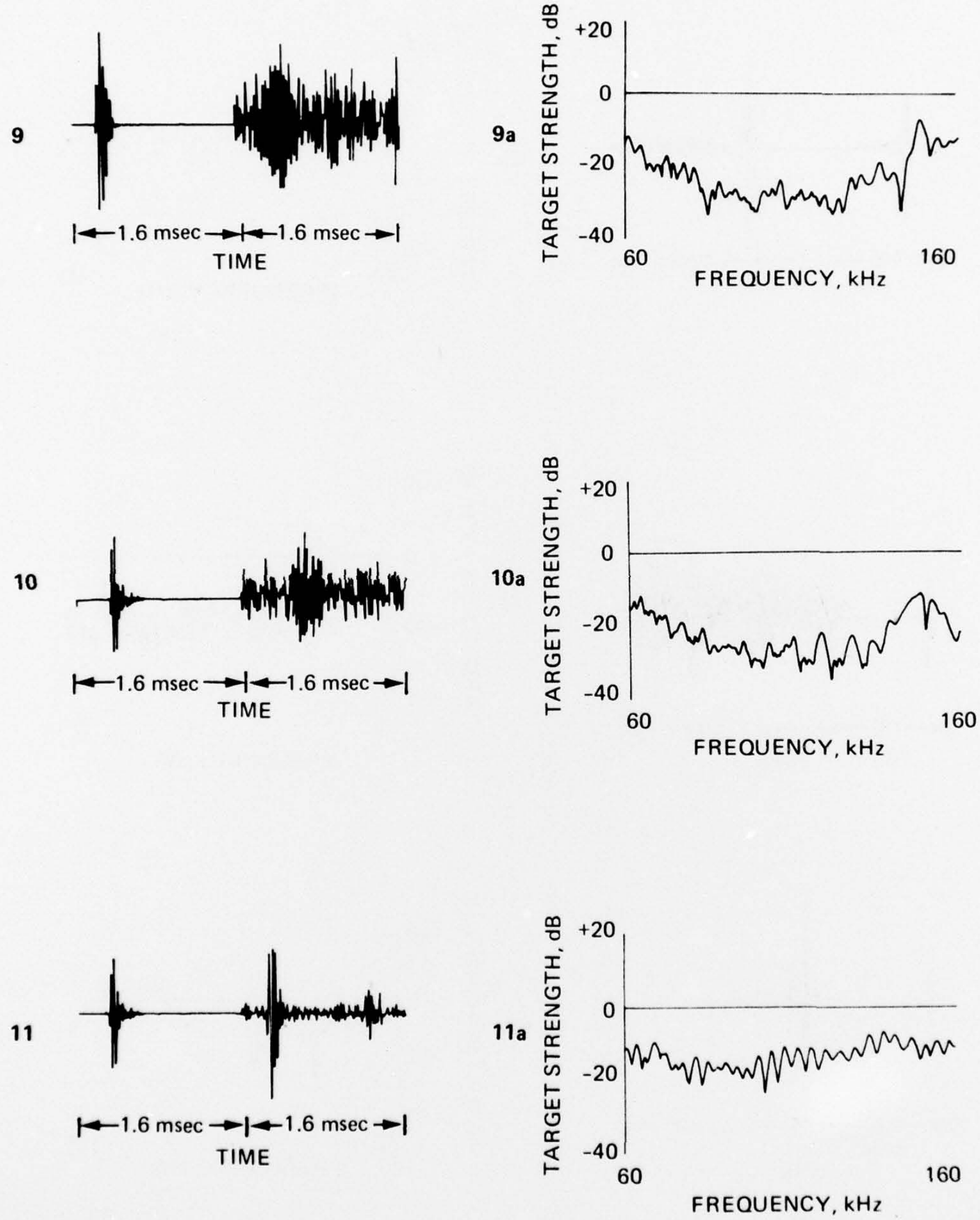

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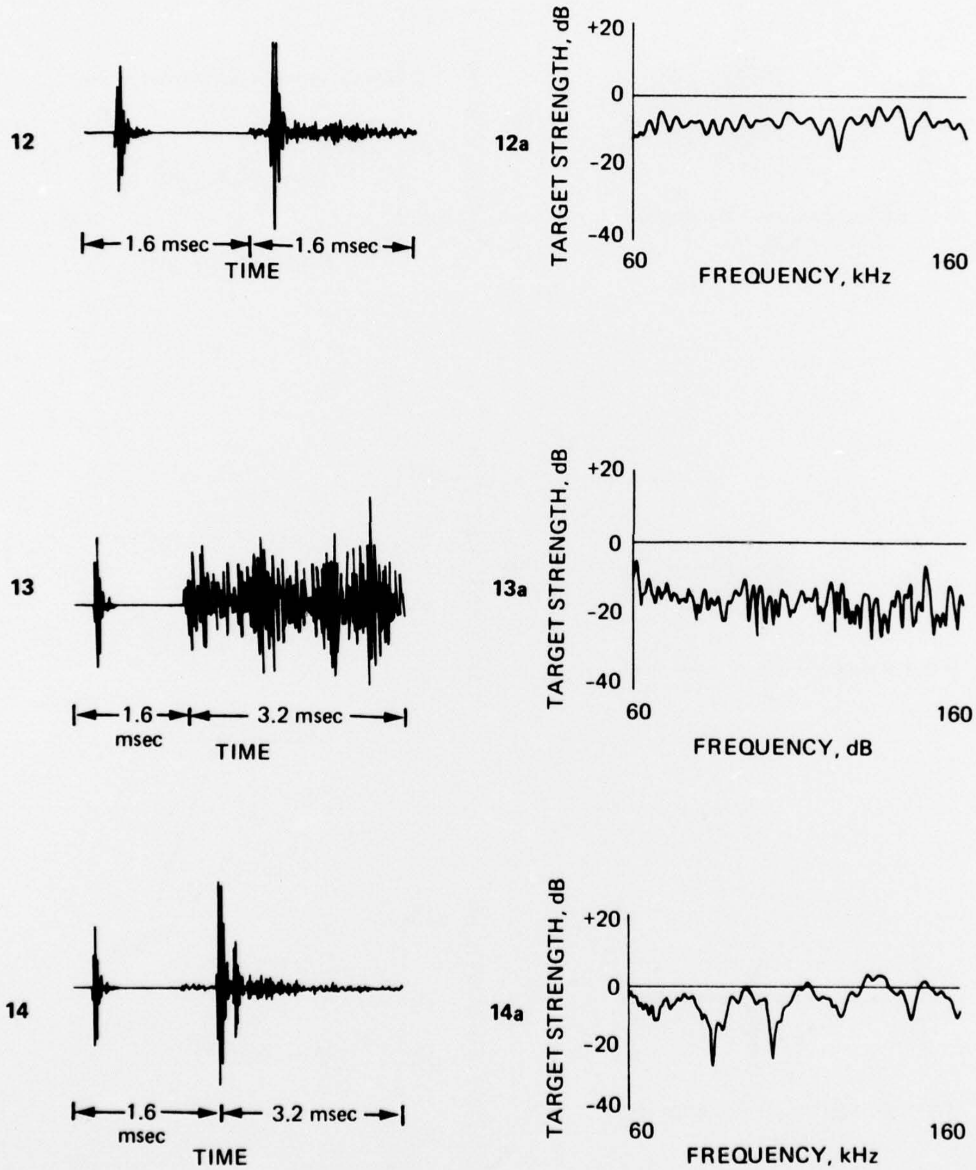

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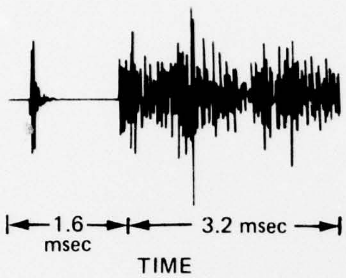

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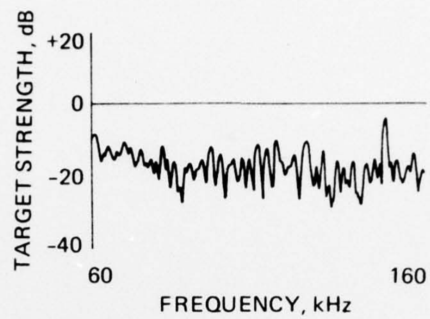

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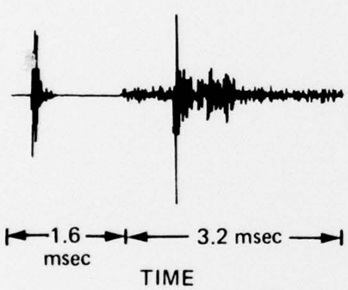

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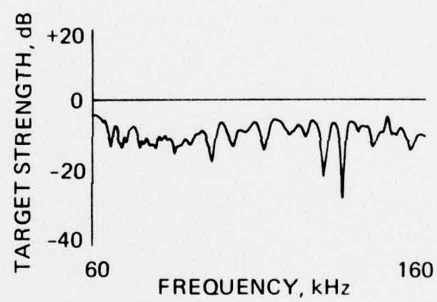

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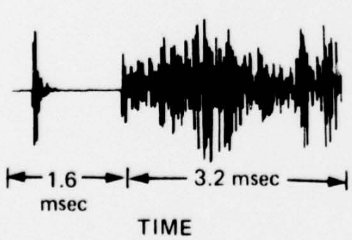

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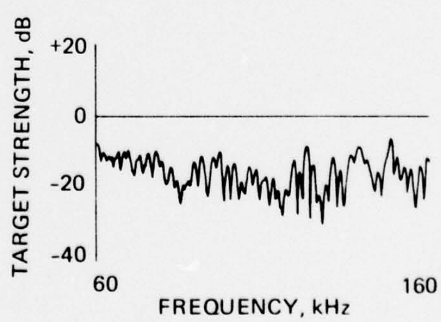

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